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STUDIES OF DISPLAY SYMBOL LEGIBILITY: XXII THE RELATIVE LEGIBILITY OF FOUR SYMBOL SETS MADE WITH A FIVE BY SEVEN DOT MATRIX

Donald A. Shurtleff

MARCH 1970

Prepared for

DEPUTY FOR TACTICAL SYSTEMS
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
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L. G. Hanscom Field, Bedford, Massachusetts

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Project 407A

Prepared by

THE MITRE CORPORATION
Bedford, Massachusetts

Contract F19(628)-68-C-0365

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FOREWORD

The investigations described in this technical report were conducted under Government Contract Number F19(628)-68-C-0365 to The MITRE Corporation, Bedford, Massachusetts.

REVIEW AND APPROVAL

Publication of this technical report does not consititute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

RALPH M. HUNT, Colonel, USAF
407L System Program Director
Deputy for Tactical Systems

ABSTRACT

Legibility comparisons were made among four 5 x 7 dot fonts. The four symbol fonts were shown under nearly optimal viewing conditions to one group of operators and under degraded viewing conditions to a second group of operators. The results showed that no one symbol set was significantly superior in legibility to any of the other sets. It was concluded that new symbols designs are needed to improve the legibility of present 5 x 7 dot symbol sets.

ACKNOWLEDGMENTS

Special thanks are given to Perryno Alexander for his care and patience in running the operators in this study. The assistance of Marion Marsetta and Claire Crook with the analysis of the data and with preparation of figures and tables for this report is gratefully acknowledged.

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SECTION I

INTRODUCTION

This paper is the second in a planned series of reports on the legibility of symbols formed from a matrix of dot elements. The present paper reports a comparison of the relative legibility of four sets of alphanumeric symbols made from a 5 x 7 dot matrix: the Lincoln/MITRE (L/M), IBM Ø29, HAZELTINE (HAZ), and a font proposed by the Diamond Ordnance Fuse Laboratory (DOFL). The last named font was designed to be easily read by both man and machine (4), although the legibility of the DOFL font for the human viewer has not been determined by objective performance tests. The Modified HAZ font is recommended for use in digital television displays(2). The IBM Ø29 is the font currently used on the IBM Ø29 key-punch machine. The L/M font was used in the first study in this series (9) and attempted to duplicatte as closely as possible the solid stroke L/M font which has been shown to be superior in legibility to a standard Leroy font (5). All four fonts are shown in Figure 1. The purpose of the present paper was to determine the relative legibility of these four fonts using human performance tests and, on the basis of the results, to make recommendations about the font or fonts which would be most legible for 5 x 7 dot matrix displays.

The findings of the first study (9) in this series on dot symbols showed that of four dot matrices evaluated, 3 x 5, 5 x 7, 7 x 11, and 9 x 15, the 5 x 7 was as legible as a 7 x 11 or 9 x 15 for most of the display conditions investigated. It was decided to conduct the present study to determine if the 5 x 7 L/M font used in the first study was the most legible among 5 x 7 fonts in current use. For example, the HAZ font had received an experimental evaluation and, on the basis of the evaluation, modifications were made in the original design to improve its legibility (2). However, the legibility of the HAZ font was not compared in that study with the legibility of other 5 x 7 fonts. Therefore, there was a possibility that the HAZ font might be superior in legibility to the 5 x 7 L/M font used in the first study or to other 5 x 7 fonts in current use. The IBM Ø29 font was included for evaluation because its widespread use in computer applications makes information about its legibility desirable. The DOFL was included for evaluation because, even though it is reputed to be easily identified by the human viewer, this fact has yet to be established by performance tests.

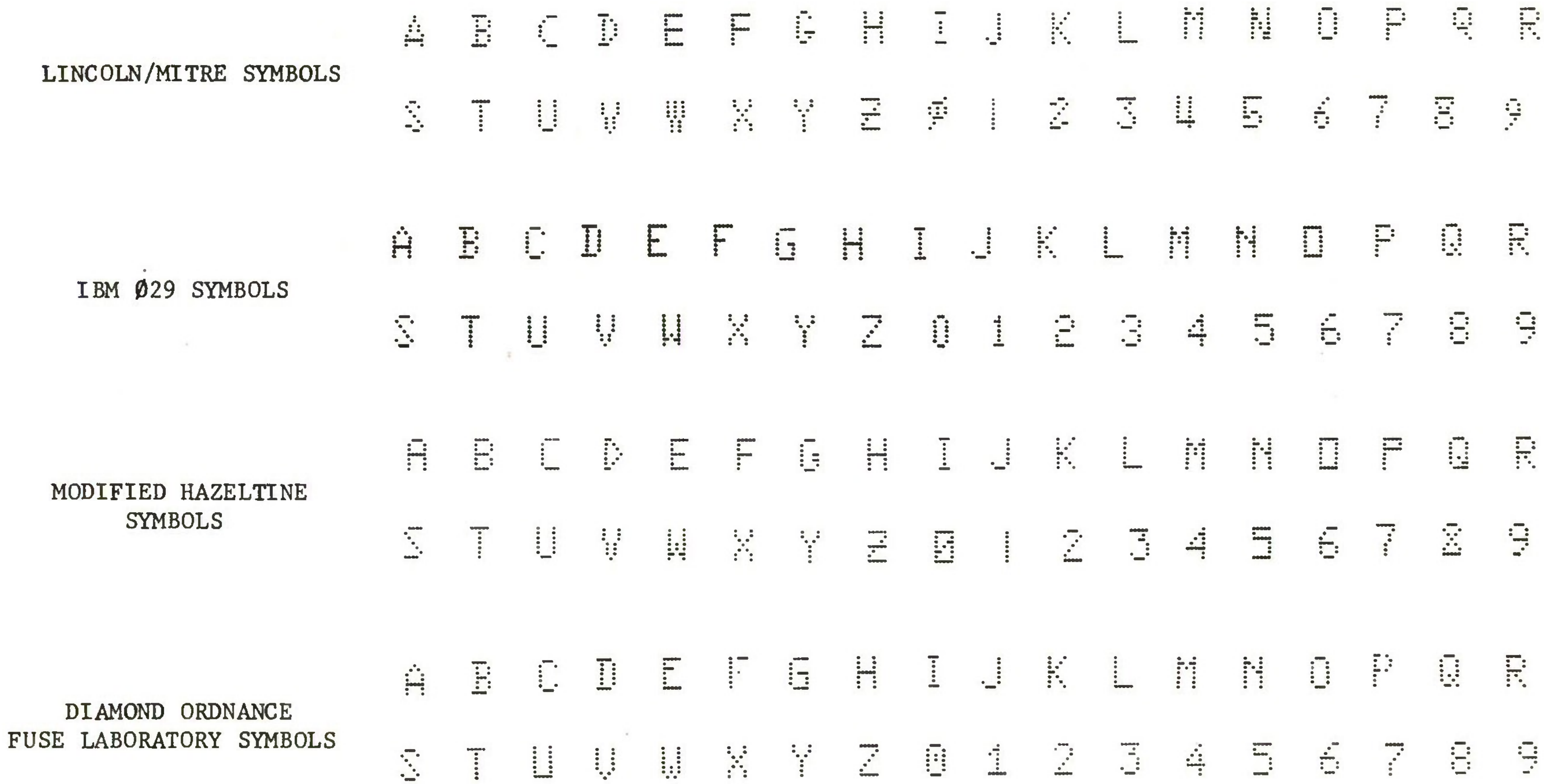

Figure 1. The four 5 x 7 fonts that were compared in legibility.

It was anticipated that if the fonts differed in legibility, the L/M and HAZ fonts would be superior to the IBM Ø29 and DOFL fonts since the design of the former two sets was based upon experimental study. At the same time, if it turned out that all four fonts were equally legible, the four fonts could be used interchangeably for display applications.

SECTION II

THE PROBLEM

A comprehensive comparison of the relative legibility of different symbol fonts must take into account factors other than different symbol geometry. Important among these additional factors are symbol degradation, operator practice, and the aspect of symbol identification performance that is recorded.

SYMBOL DEGRADATION

The selection of a particular font may depend upon the amount of symbol degradation that is anticipated. For example, under nearly optimal* display conditions these fonts may not differ in legibility. Superior performance with one font may be demonstrated only when display quality is degraded. Two display conditions were used in the present study: a nearly optimal condition in which the visual size of the symbols was large (symbol height subtended 22 min. of arc at the operator's eye) and a degraded condition in which the visual size of the symbol was small (symbol height subtended 6 min. of arc at the operator's eye).

It is well known that symbol quality may be degraded in many ways besides reducing the visual size subtended by the symbols. The display design engineer who is faced with other kinds of possible symbol degradation (e.g., blurring) might well ask if the findings for these four fonts may be applied when symbols are degraded in these other ways. While an unequivocal "yes" cannot be given to the preceding question, there is some evidence that a font which is superior in legibility to another font in one kind of degrading situation will retain its superior legibility over the other font in other kinds of degrading situations (8). At least it could be argued that, although a font may not retain its superior legibility in all kinds of degrading situations, it probably will not reverse itself and be superior in legibility in one degrading situation and inferior in legibility in a second degrading situation.

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*Although the word "optimal" is difficult to define, it is intended to describe a set of display values which have previously been shown to produce good symbol legibility.

OPERATOR PRACTICE

The superiority of one font over another may not be apparent or realized until the operator has had an opportunity to learn the distinctive features of the superior font. Consequently, the operators in the present study were given two sessions on each of the four fonts. Preliminary study has indicated that the major improvement in operator performance occurs from the first to second sessions with little additional improvement occurring for sessions following the second.

IDENTIFICATION PERFORMANCE

Many previous studies (6) have shown that the aspect of identification performance that is recorded is important. For example, the percentage of errors for two symbol fonts may be the same for a given display situation, but symbols of one of the fonts may be identified at a faster rate than symbols of the second font. In the present study, two aspects of the operator's identification responses were recorded; the accuracy of identification, and the rate of identification.

SECTION III

DETAILS OF THE EXPERIMENT

APPARATUS

The apparatus was the same as that used in the first study in this series and consisted principally of a PDP-8 computer and a Tektronix type RM 503 oscilloscope (DEC type 34) fitted with a P-7 phosphor. The computer was used to construct the symbols, generate symbol sequences, and arrange the symbol sequences so that nine symbols could be displayed in a 3 x 3 array on the oscilloscope.

OPERATORS

Eight MITRE employees served as operators. All operators had 20/20 near and far acuity, normal phoria, normal depth perception and normal color vision as determined by the Bausch and Lomb Ortho-Rater.

SYMBOL PROPERTIES

The height of the 5 x 7 matrix out of which symbols in each of the four fonts were constructed was .150 in. and its width was .092 in. The height-to-width ratio of the matrix was 1.63 and the stroke width of the symbols was .024 in.

The luminance of dots making up symbols in each of the fonts ranged from 14 to 16 ft.-L as measured with a Spectra Pritchard photometer with an aperture of 2 min. of arc.

PROCEDURE

The eight operators were randomly assigned to one of two groups, A or B. Group A viewed symbols from a far position where the height of the symbols subtended 6 min. of arc at the operator's eyes. Group B viewed the symbols at a near viewing position where the height of the symbol subtended 22 min. of arc at the operator's eyes. Thus, Group A identified symbols under degraded viewing conditions (small symbol size) while Group B identified symbols under nearly optimal viewing conditions (large symbol size).

Each operator had eight experimental sessions. In the eight sessions, he saw each of the four fonts two times. The orders in

which the fonts were assigned to the operators for the first four sessions are shown in Table I. In the orders of assignments shown in Table I, each font appeared an equal number of times in each ordinal position, and each font was preceded and followed an equal number of times by each of the other fonts. This assignment of fonts guarded against the possibility that a given font might either suffer or excel because it was always preceded by the same font.

In the remaining four experimental sessions, the sequence shown in Table I was repeated for each of the eight operators.

In each session, the operator was first familiarized with every symbol in the font he was to see for that session. The symbols were presented one at a time on the oscilloscope, and the operator was free to study each symbol for as long as he liked. In addition, he was given a photograph of the symbol set which he was free to study during breaks in the test run.

Following familiarization, the operator was given the test runs in which he saw 20 arrays of symbols in succession. Over the 20 arrays, each of the 36 alphanumeric symbols was presented five times. The symbols were assigned to arrays by a procedure that ensured random symbol sequences. Each array contained nine symbols arranged in three rows and three columns. In a given array, the symbols were spaced horizontally 50 percent of symbol height and vertically 100 percent of symbol height. Both horizontal and vertical spacing refer to distances measured from the outer edges of the symbols. While making his identification, the operator was seated at a modified typewriter table equipped with a headrest and eye shield, which obscured his peripheral vision. The operator was asked to read each array as fast and as accurately as possible. He was instructed to identify the symbols in a normal reading fashion, namely left to right and top to bottom. The time to read each symbol array was recorded. The operator's symbol identifications were tape-recorded and the tape was scored later to determine his identification accuracy.

The sessions were conducted in a sound-deadened room. The room was illuminated by overhead fluorescent lights. Ten ft.-c of light fell at the operators' station and 15 ft.-c of light fell at the scope face. The scope face was hooded, and reflecting objects were shaded so that there were no reflections off the scope face to annoy or distract the operator.

TABLE I

The Orders in Which Operators in Group A and B Identified Symbols in Each of the Four Different Fonts

		ORDERS			
		1st	2nd	3rd	4th
Operators	O_1	L/M	IBM	HAZ	DOFL
	O_2	IBM	DOFL	L/M	HAZ
	O_3	HAZ	L/M	DOFL	IBM
	O_4	DOFL	HAZ	IBM	L/M

SECTION IV

RESULTS AND CONCLUSIONS

GROUP A (Small Symbol Size)

Rate of Symbol Identification

It is apparent from Fig. 2 that CI/min. is approximately the same for each of the four fonts for both the first and second session. Statistical analysis* showed that symbol font was not a significant source of variance (Table II). Sessions were a significant source of variance, which indicates that the rate of correct symbol identification increased significantly from the first to the second session.

Conclusions

It is concluded that, when display quality is degraded, the four fonts do not differ in the rate at which operators are able to make correct identifications for the identification task studied. Rate of correct symbol identification will increase if the operator is given practice in identifying the symbols of these fonts.

Percentage of Error

The percentage of errors of identification for Group A are shown in Fig. 2. Fig. 2 seems to indicate that fewer errors occurred for the L/M and IBM fonts than for the HAZ or DOFL fonts, particularly in the first session. However, the analysis of variance of these data (Table III) showed that symbol fonts were not a significant source of variance. Also, although Fig. 2 seems to show some increase in accuracy of symbol identification with practice (decreased percentage of error), at least for the DOFL and HAZ fonts, Table III indicates that this improvement was not statistically significant.

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*The analysis of variance model used in the present study is described in reference (3) under mixed models Case VII.

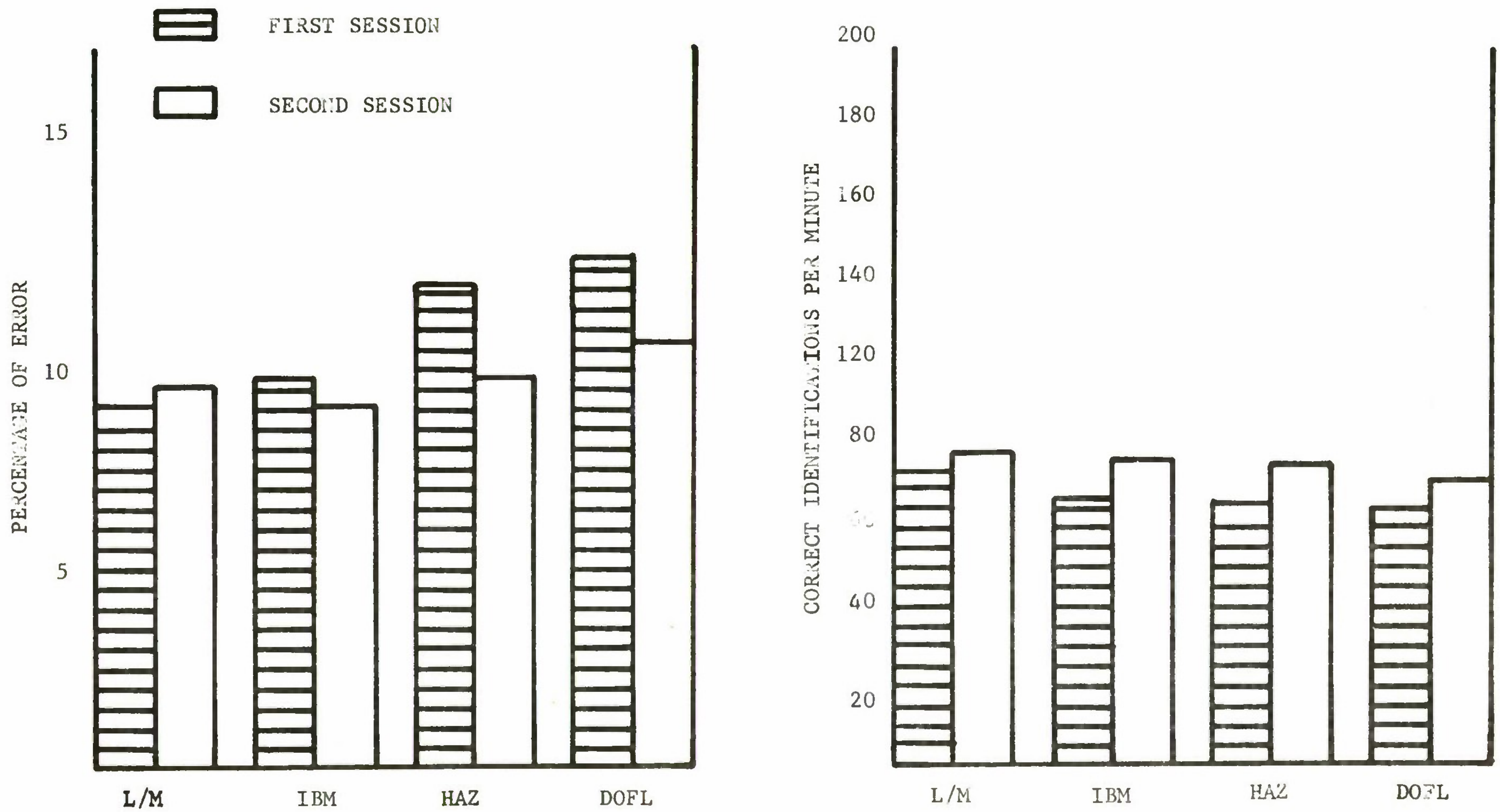

Figure 2. Percentage of error and correct identification per minute for Group A for the first and second sessions.

TABLE II

Analysis of Correct Identifications Per Minute for Group A

Source of Variance	Variance	df	MS	F	P
Fonts	262.56	3	87.52	1.01	N.S.
Sessions	482.05	1	482.05	29.62	.01
Operators	4322.28	3	1440.76		
F x S	34.24	3	11.41	.26	N.S.
F x O	782.30	9	86.92		
S x O	48.82	3	16.27		
F x S x O	393.39	9	43.71		

TABLE III

Analysis of Percentage of Error for Group A

Source of Variance	Variance	df	MS	F	p
Fonts	35.47	3	11.82	1.25	N.S.
Sessions	10.93	1	10.93	2.21	N.S.
Operators	1029.51	3	343.17		
F x S	10.42	3	3.47	1.05	N.S.
F x O	84.95	9	9.44		
S x O	14.81	3	4.94		
F x S x O	29.65	9	3.29		

Conclusions

It is concluded that when display quality is degraded, the four fonts do not differ in percentage of error for the identification task studied. Percentage of error will not decrease with practice, at least for the amount and type of practice given in the present study.

Symbol Confusions

The inter-symbol confusions for each font for both the first and second sessions are shown in Tables IV through XI. These confusion matrices provide two important pieces of information about each of the four fonts. First, a comparison of the inter-symbol confusions for a given font for the first and second sessions indicates which symbol confusions were eliminated or greatly reduced by practice, and which confusions were not reduced by practice. For example, a comparison of Tables VI and VII of confusions for the IBM Ø29 font shows that the confusion of the M with the H was greatly reduced by practice (10 errors reduced to 3) while the confusion of the 8 with the Ø (4 errors increased to 5) and Q (3 errors reduced to 2) was not reduced by practice. Second, the confusion matrices indicate which symbol designs should be changed to make each of the fonts more legible. That is, if a symbol is a major source of error even after practice, the geometry of the symbol must be changed in order to improve its legibility. For example, a comparison of Tables IV and V of confusions for the L/M font suggests that the geometry of the L/M W or V, or both, should be changed to eliminate the confusion between the W and V. These are merely examples of information provided by confusion matrices and major symbol confusions of this type occurred for all four fonts. Major symbol confusions of this type will be considered in detail in the next section (Section V).

Conclusions

The concentration of errors in only a few symbols in each of the four fonts suggests that the legibility of each of the symbol sets could be improved by changing the design of these symbols. (See Section V)

Character Called (columns) / **Character Shown** (rows)

Shown \ Called	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	1	2	3	4	5	6	7	8	9	Ø	Σ
A																																					
B				2																																	2
C																																					
D																																					
E																										1											1
F																																					
G																																1					1
H													1	2																							3
I																											1										1
J																																					
K																																					
L																																					
M								4																													4
N																														1							1
O																																				3	3
P																																					
Q																																					
R																																					
S																																					
T																																					
U																																					
V																									2												2
W																						4			3									1		1	9
X																																					
Y																						2															2
Z																												2									2
1									3																												3
2																			2							1			1		1						5
3										1									4																		5
4																					3		1														4
5							5												2																		7
6																																					
7																																					
8																			4									1			3						8
9																1																				1	2
Ø																1																					1
Σ				2			5	4	3	1			1	2		2			12		3	6	1		5	2	1	3	1	1	4	1		1		5	66

TABLE IV. Intersymbol Confusions for the L/M Font for the First Session.

Character Called

Character Shown	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Ƶ	1	2	3	4	5	6	7	8	9	Ø	Σ
A																																					
B				4																																	4
C																																					
D																																					
E																																					
F																																					
G																																					
H													2	1																							3
I																																					
J							1																														1
K																																					
L																																					
M								7						1																							8
N								1																						1							2
O																																				4	4
P																																					
Q																																			2		2
R																																					
S																												1			1						2
T																																					
U																																					
V		1																																			1
W																						12															12
X																																					
Y																																					
Ƶ																												4									4
1									5																												5
2																																					
3																			1												1						2
4																	1				3																4
5							5																									2					7
6																														1							1
7																																					
8		1																	1										1		1						4
9																																				1	1
Ø															1																				1		2
Σ		2		4			6	8	5				2	2		1	1		2		3	12						5	1	2	3	2			3	5	69

TABLE V. Intersymbol Confusions for the L/M Font for the Second Session.

Character Called

Character Shown	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	1	2	3	4	5	6	7	8	9	Ø	Σ
A																																					
B				5																																	5
C																																					
D																																					
E																										1											1
F																																					
G																																					
H														3									1														4
I																											4										4
J																																					
K																																					
L																																					
M								10						1				1					1														13
N								2																													2
O				2													1			1																	4
P																																					
Q															2				1																	1	4
R																																					
S																																					
T																																					
U																																					
V																					1				1												2
W								2					1								6																9
X																																					
Y																																					
Z																												4									4
1									2																												2
2																																					
3																																					
4																																					
5																			5																		5
6																																					
7																																					
8															1		3		1																	4	9
9																																					
Ø				1											2																						3
Σ				8				14	2				1	4	5		4	1	7	1	7		2		1	1	4	4								5	71

TABLE VI. Intersymbol Confusions for the IBM Font for the First Session

Character Called

Character Shown	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Ƶ	1	2	3	4	5	6	7	8	9	Ø	Σ
A																																					
B				4																															1		5
C																																					
D																																					
E																																					
F																																					
G																																					
H																																					
I																											2										2
J																																					
K																																					
L																																					
M								3						1									2														6
N								1					5																								6
O				3													1																			2	6
P																																					
Q							1								5																					1	7
R																																					
S																															1						1
T																																					
U																						1															1
V																					2				2												4
W																					6																6
X																																					
Y																																					
Ƶ																												5									5
1									2																												2
2																																					
3																			1																		1
4																																					
5																			1																		1
6																																					
7																																					
8							1										2																			5	8
9				1																																	1
Ø				1											3																						4
Σ				9			2	4	2				5	1	8		3		2		8	1	2		2		2	5			1				1	8	66

TABLE VII. Intersymbol Confusions for the IBM Font for the Second Session.

Character Called

Character Shown	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Ƶ	1	2	3	4	5	6	7	8	9	Ø	Σ
A														1				2																			3
B																																					
C																																					
D																																					
E																																					
F																																					
G																																1					1
H														2									1														3
I																											1										1
J																																	1				1
K																																					
L																																					
M								5						1																							6
N								4					1																								5
O		1															3																				4
P						1																															1
Q							4								2																						6
R																																					
S																															4						4
T																																					
U																																					
V																									4												4
W								5					1	2																							8
X														1																							1
Y																																					
Ƶ																												6									6
1									1																												1
2																										7											7
3																			1																		1
4																																					
5																																					
6							1																														1
7																																					
8		1																	1			1				1		9	2								15
9																																					
Ø		4		1											2		1						1														9
Σ		6		1		1	5	14	1				2	7	4		4	2	2			1	2		[illegible]	8	1	15	2		4	1	1				88

TABLE VIII. Intersymbol Confusions for the HAZ Font for the First Session.

Character Called

Character Shown

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	1	2	3	4	5	6	7	8	9	Ø	Σ
A																		2																			2
B				1																																1	2
C																																					
D																																					
E																																					
F																																					
G																																1					1
H													1	6																							7
I																																					
J																																					
K																																					
L																																					
M								1						3																							4
N								5					3																								8
O				1																																	1
P																																					
Q							2								4																						6
R																																					
S																															2						2
T																																					
U																																					
V																									2												2
W													2	2							1																5
X																																					
Y																																					
Z																												4									4
1									6																												6
2																										3											3
3																																					
4																																					
5																																			1		1
6							1																														1
7																																					
8																			3							1		5									9
9																																					
Ø		2													5																						7
Σ		2		2			3	6	6				6	11	9			2	3		1				2	4		9			2	1			1	1	71

TABLE IX. Intersymbol Confusions for the HAZ Font for the Second Session.

Character Called

Character Shown	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Ƶ	1	2	3	4	5	6	7	8	9	Ø	Σ
A																		1																			1
B				6																															2		8
C																																					
D		1																																			1
E												1																									1
F																																					
G																																2					2
H													3	1																							4
I												1															4										5
J																																					
K																																					
L																																					
M								8			1			2				1																			12
N													1																								1
O																	1																			2	3
P																																					
Q															7																					1	8
R																																					
S																																					
T																																					
U																																					
V																					6																6
W																					13	3															16
X																																					
Y																																					
Ƶ																												5									5
1									1			1																									2
2																																					
3																			2																		2
4																																					
5																																					
6																																					
7																																					
8		1					1								2				2																2	2	10
9																																					
Ø				1											5																						6
Σ		2		7			1	8	1		1	3	4	3	14		1	2	4		19	3					4	5				2			4	5	93

TABLE X. Intersymbol Confusions for the DOFL Font for the First Session.

Character Called

Character Shown	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Ƶ	1	2	3	4	5	6	7	8	9	Ø	Σ
A																																					
B				6												1												1									8
C																																					
D																																					
E			1																																		1
F																																					
G																																1					1
H														1																							1
I																											4										4
J																																					
K																																					
L																																					
M								3						4																							7
N								2					2																								4
O																																		1		2	3
P																																					
Q															5																						5
R																																					
S																													1								1
T																																					
U																																					
V																					3																3
W																					7	4															11
X																																					
Y																																					
Ƶ																												7									7
1																																					
2																																					
3																			1																		1
4																																					
5																			2																		2
6																																					
7																																					
8		1					2																													8	11
9																																					
Ø															4																			4			8
Σ		1	1	6			2	5					2	5	9	1			3		10	4					4	8	1			1		5		10	78

TABLE XI. Intersymbol Confusions for the DOFL Font for the Second Session.

GROUP B (Large Symbol Size)

Rate of Symbol Identification

The rate of correct identifications per min. (CI/min) at which operators in Group B were able to identify symbols in the four fonts is shown in Fig. 3. It is apparent from Fig. 3 that some differences among fonts in CI/min occurred for both the first and second session; the fastest overall rate (average for first and second session) occurred for the L/M font and the slowest for the HAZ. When CI/min for the four fonts for the two sessions were submitted to an analysis of variance, symbol fonts were found to be a significant source of variance (Table XII). However, a follow-up analysis of differences between pairs of fonts using the least conservative (t) test* revealed that no one font was significantly superior to any of the other fonts. Thus, even the largest mean difference between two fonts (L/M vs. HAZ) was not statistically significant when the (t) test was applied.

Sessions were not a significant source of variance even though Fig. 3 seems to show that performance for all fonts improved from the first to the second session.

Conclusions

It is concluded that when display conditions are nearly optimal, the four symbol fonts differ in the rate at which operators are able to make correct symbol identifications for the identification task studied, although the superiority of one font over the others was ambiguous statistically. Practice did not increase symbol identification rates significantly.

Percentage of Error

The percentage of errors in identification for Group B is shown in Fig. 3. Fig. 3 indicates that when the visual size subtended by the symbols is large, errors of identification are negligible for each of the four symbol fonts for both the first and second sessions. It is evident by visual inspection alone that the fonts do not differ in errors or identification at 22 min. of arc.

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*See reference (10) for an evaluation and comparison of tests for determining the significance of differences between individual means.

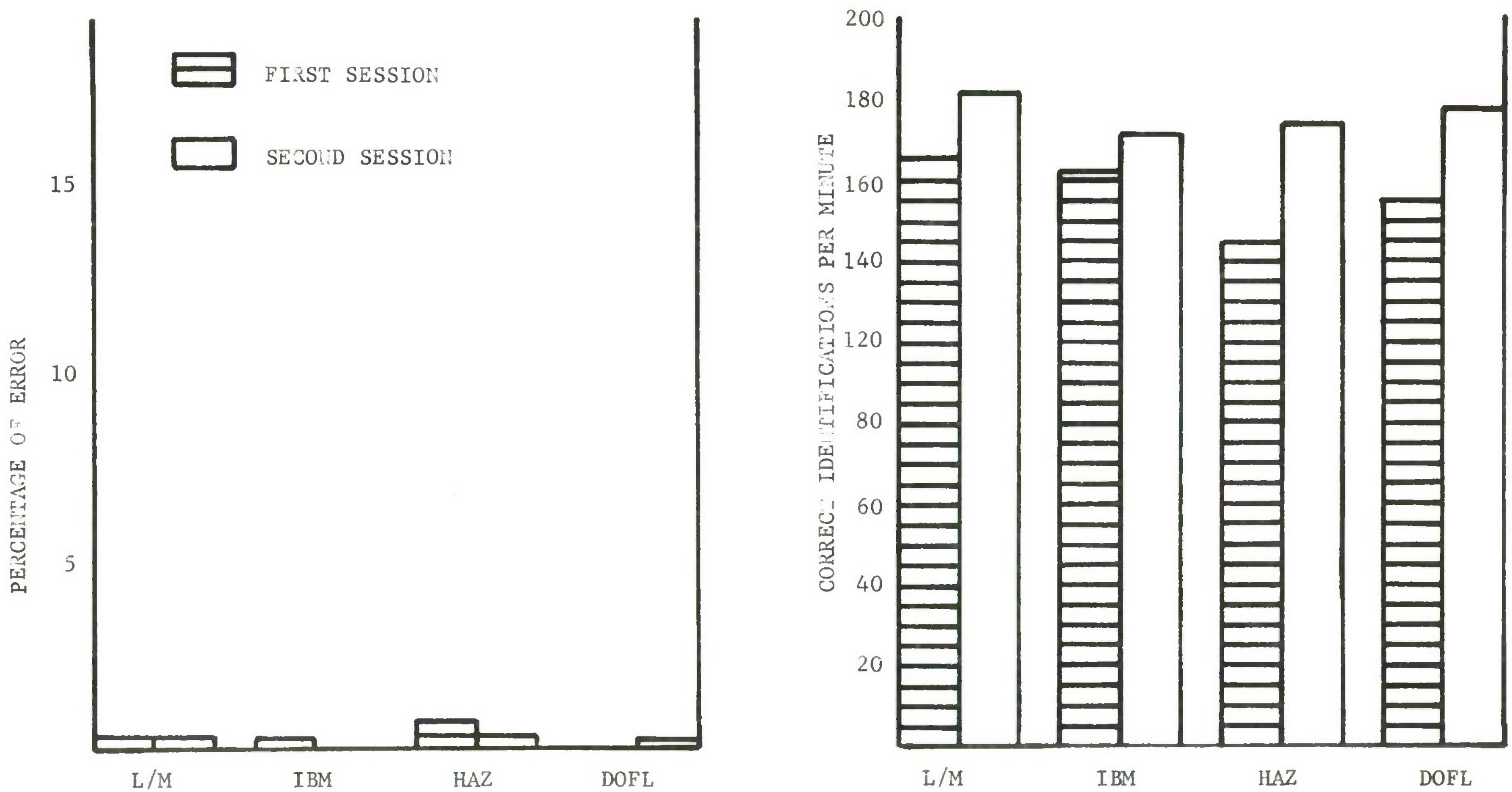

Figure 3. Percentage of error and correct identifications per minute for Group B for the first and second sessions.

TABLE XII

Analysis of correct identifications per minute for Group B

Source of Variance	Variance	df	MS	F	P
Fonts	865.11	3	288.37	5.50	.05
Sessions	3007.00	1	3007.00	4.78	N.S.
Operators	58394.55	3	19464.85		
F x S	496.45	3	165.32	.78	N.S.
F x O	492.14	9	52.46		
S x O	1888.24	3	629.41		
F x S x O	1877.25	9	210.86		

Conclusions

It is concluded that when display conditions are nearly optimal, the four fonts do not differ in percentage of error of identificacion for the identification task studied.

Symbol Confusion

The errors among symbols for each of the four fonts were too few to be reported in confusion matrices.

SECTION V

DISCUSSION OF RESULTS

SYMBOL DESIGN CHANGES

A systematic approach for identification and selection of particular symbols whose geometry should be changed to improve the legibility of a symbol set requires the adoption of a set of symbol selection criteria. The ones selected in the present case are that (a) in the second session the symbol had to contribute 5% or more to the total error for that session and (b) the reduction in total error for the symbol from the first to the second session did not exceed 50%. These two criteria take into account two important considerations; first, the symbol was a major source of error for the symbol set since it contributed 5% or more to the total error, and second, since the errors were not greatly reduced from the first to second session, it is not likely that the errors were caused by the operators' lack of familiarity or practice with the symbol design, but more likely by the geometry of the symbol.

Applying the above criteria to the four symbol sets of the present study indicates that the geometry of the following symbols from each of the symbol sets should be changed:

a. L/M font; the W (17.4)*, M (11.6), 5 (10.1), 1 (7.2), B (5.8), O (5.8), Z (5.8), and 4 (5.8).

b. IBM font; the 8 (12.1), Q (10.6), N (9.1), O (9.1), Z (7.6), B (7.6), V (6.1), and Ø (6.1).

c. HAZELTINE font; the 8 (12.7), N (11.3), H (9.8), Ø (9.8), Q (8.4), and 1 (8.4).

d. DOFL font; the 8 (14.1), N (14.1), B (10.2), Ø (10.2), Z (9.0), I (5.1), and N (5.1).

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*In parenthesis is percent of total error for second session contributed by that symbol.

SECTION VI

LIMITATIONS

RATE OF IDENTIFICATION

It may have occurred to the reader that the failure to find statistically reliable differences between pairs of fonts might have resulted from the operators reaching the upper limit in their ability to read symbols aloud. If the operators had reached the upper limit in their performance, then it could be argued that the failure to find reliable differences between pairs of fonts occurred because the operators did not have the ability to read the easier font(s) any faster than the more difficult font(s). The best evidence against the argument of a performance limitation on the results of this study comes from the findings of a previous, unpublished study (7) which showed that operators' reading rates for good quality, solid-stroke symbols were much faster than the fastest reading rates attained in the present study. In that previous study, identification rates of approximately 200 CI/min. were attained, while in the present study the highest rates were approximately 180 CI/min. Consequently, it is unlikely that the failure to find differences between pairs of fonts happened because the operators were limited in their ability to identify symbols.

It still could be argued, of course, that statistically reliable differences between pairs of fonts might be found if other symbol identification tasks were used. Again, the best evidence against the argument of a task by font interaction comes from the findings of previous studies. One of these previous studies (8) showed that several tests involving relatively simple visual-motor tasks (like that of the present study) were correlated; they led to similar conclusions about the relative legibility of symbol sets.

A study by Gibney (1) showed that more "complex"* visual-motor tasks failed to show differences in the relative legibility of

*The author of the study is not clear in his definition of the word "complex". However, his definition of "complex" tasks included making a finger-operated key response to identify symbols, with a different key response being required for each symbol in the set while his definition of elemental tasks includes verbal identification of tachistoscopically presented symbols.

symbol sets, while statistically significant differences between these same sets were found with more elemental visual-motor tasks. In other words, it appears that, if a difference in legibility cannot be demonstrated by use of elemental tasks, the difference is even less likely to be demonstrated when more complex tasks are used.

In summary, while the evidence cited does not rule out completely the notion that other identification tasks might show a difference between the fonts investigated in the present study, this notion seems unlikely for two reasons; (a) elemental visual-motor tasks like that of the present study are correlated in their findings and (b) more complex tasks, like those used by Gibney (1), are apparently even less sensitive than elemental tasks in showing differences in legibility among fonts.

CONSTRAINTS ON 5 x 7 SYMBOL DESIGNS

The first study in this series (9) on dot symbols showed that the rate of CI/min. for a 7 x 11 matrix was superior to that for the 5 x 7 matrix. On the basis of these previous findings one might question the value of additional research to evaluate and possibly improve 5 x 7 symbol sets, the reason being that the data to date suggests that maximally legible symbols can be achieved only with a dot matrix larger than the 5 x 7. While on the surface this question seems reasonable, it will be recalled that the purpose of the present study was not to discover a symbol set of maximal legibility, but instead to discover the most legible 5 x 7 font of those currently available.

Two reasons were given for the investigation of 5 x 7 fonts. First, the 5 x 7 dot matrix is the most commonly used in current displays, and present dot-symbol practices would benefit from knowledge about the relative legibility of 5 x 7 symbol sets. Second, the first study showed that, for most of the display conditions studied, symbol identification would not be improved by use of a 7 x 11 matrix in place of the 5 x 7*. Thus, for many display conditions, the operators' performance probably would not improve even if more dots were available for symbol construction.

*The 7 x 11 matrix was superior to the 5 x 7 matrix only when the operator was given practice with the symbol sets, the symbol height subtends a large size (22 min. of arc at the operator's eye), and performance was expressed in CI/min.

The latter fact suggests, but does not prove conclusively, that for these same display conditions, identification performance would also not be improved by changes in 5 x 7 dot designs. While the suggestion that it is not possible to improve 5 x 7 fonts for many display conditions seems reasonable, there is, on the other hand, the danger that, in the absence of data like that supplied by the present study, display designers might select a symbol font which would impair operator performance under these same display conditions. Also, there is a possibility that, for the one display condition where performance was better for the 7 x 11 than for the 5 x 7, careful selection of a 5 x 7 design would give performance more nearly like that attainable with a 7 x 11 matrix.

Although the present study showed that performance for none of the four 5 x 7 symbol sets approached that attained with a 7 x 11 matrix, it still may be possible to improve the design of existing 5 x 7 fonts, as suggested by the analysis of intersymbol confusions of the present study.

In the next (third) study in this planned series of reports, the design of the L/M symbols will be changed as indicated by the analysis of the inter-symbol confusions of the present study. The new symbol designs will be compared with the L/M designs used in the present study to see if the new changes in symbol design improve the legibility of the L/M, 5 x 7 font.

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13. ABSTRACT

Legibility comparisons were made among four 5 x 7 dot fonts. The four symbol fonts were shown under nearly optimal viewing conditions to one group of operators and under degraded viewing conditions to a second group of operators. The results showed that no one symbol set was significantly superior in legibility to any of the other sets. It was concluded that new symbols designs are needed to improve the legibility of present 5 x 7 dot symbol sets.

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